A Presentation to the NOAA Science Advisory Board

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Outline

- Purpose
- Issue
- Background & Discussion
- Desired Outcome

Purpose

- Review progress of NOAA's Hurricane Forecast Improvement Project (HFIP)

- Update SAB on response to NOAA SAB Hurricane Intensity Research Working Group (HIRWG) Recommendations

Issue

- Risks to life and property from hurricanes have escalated as people continue to move to the coasts and as the value of coastal infrastructure and economic activity continues to rise.

- NOAA reduced track errors by about 50% over the last 20 years, but little progress was made to reduce the intensity forecast error.

  NOAA is leading an aggressive effort with commensurate investments to significantly improve its hurricane forecasting capability.

Background

- September, 2005 – Hurricanes Katrina and Rita

- October 2006 – NOAA SAB Hurricane Intensity Research Working Group (HIRWG) Report Released

- January 11, 2007 National Science Board Report on the need for an National Hurricane Research Initiative

- June 2007 – NOAA Hurricane Forecast Improvement Project (HFIP) Established

- July 2008 – FY2009 President's Budget amended to include +$13M for HFIP

NOAA HFIP Purpose

- Unify the NOAA effort

- Provide the basis for NOAA co-leading with NSF, Navy and others in a national effort to:

  - Develop a National Hurricane Research Agenda to provide new science

  - Apply new science and technology to the operational hurricane and storm surge warning and forecast problem

- Significantly improve guidance to NHC [and Joint Typhoon Warning Center (JTWC)] for hurricane track and intensity forecasts

Significantly improve NOAA's forecast services
for tropical storms and hurricanes
through
improved hurricane forecast science and technology

NOAA's HFIP Leadership

- Hurricane Executive Oversight Board:

  - Jointly chaired by AA for Weather Services and AA for Oceanic and Atmospheric Research

  - Cross-NOAA Membership

- HFIP Management:

  - Project Manager: Fred Toepfer, NWS

  - Development Manager: Dr. Bob Gall, NCAR

  - Research Lead: Frank Marks, OAR

  - Operational Lead: Ed Rappaport, National Hurricane Center

NOAA HFIP Vision

- **A National Hurricane Forecast System (NHFS)** focused on providing accurate and reliable forecast guidance to NHC out to 5-7 days:
  - Multi-component global and storm scale atmospheric, wave and oceanic modeling system -- to accurately and reliably model both the hurricane, its intensity, and the environmental controls on storm evolution over time
  - Managed ensemble diversity to:
    - Provide 'Most Probable" outcome
    - Quantify, bound, and reduce forecast uncertainty
  - Optimal use of existing and planned observing systems
  - Advanced forecast techniques for forecaster use in translating forecast guidance into forecast and warning services

Key NOAA HFIP R&D Priorities

- **Focused research and development** effort to improve NOAA's overall ability to predict tropical storms and hurricanes:

  - Better understanding and model representation of dynamics and physics driving the intensification and weakening of storms
  - Better understanding and model representation of interaction of storm with its environment – ocean, atmosphere, land
  - Better data assimilation, storm characterization and specification of initial state through:
    - **Better use of existing and planned/programmed observing systems and strategies**
    - **Identification of data gaps**
  - Improved specification and characterization of forecast through the use of probabilistic techniques

Key NOAA R&D Priorities
Technology Development and Transition to Operations

- **Transition research from all sources, federal and academic, to operations** through forecast technology development, test, and evaluation:

  - Implement global and storm-scale high-resolution modeling technology

  - Accelerate evolution of storm scale operational modeling technology -- using NOAA sustained operational HPC

  - Global and hurricane model data assimilation

  - Transition into operations appropriate (bathymetry, tides, freshwater) upgrades to storm surge modeling system

  - Accelerate development and transition to operations of advanced forecast techniques

A balanced approach to research and development and transition to operations of hurricane forecast technology

Engagement with External Community

- Office of the Federal Coordinator for Meteorology/NSB/NOAA SAB Hurricane Intensity Research Working Group (HIRWG) Reports
- April 4, 2008 the University Corporation for Atmospheric Research (UCAR) coordinated a national summit of key federal and academic research leadership
  - *Form a national research partnership focused on break-through improvements in hurricane forecasting*
- May 2008 - Released Up-dated HFIP Plan for public comment
- Supported UMD/UW effort for NSF Science and Technology Center
- 3-year National Ocean Partnership Program (NOPP) BAA for Hurricane Intensity Research; awarded 2.5M for first year in Sept. and Oct. 2009
- Direct support to academic partners (Penn. State, Wisconsin, NCAR)
- Developing partnership with Office of Naval Research and Naval Research Laboratory
- Directed Research effort - UMD, FIU, U. South Ala. on Hurricane intensity
- Directed Research on ocean interaction (URI), cloud products (UMD), and ensemble data assimilation (Cooperative Institute for Research in the Atmosphere/CSU).

NOAA Hurricane R&D Funding

	2007	2008	2009	2010	2011
Hurricane Research (HRD)	$4M	$6M	$6M	$6M	$6M
JHT (USWRP)	$1.3	$1.5	$1.5	$1.5	$1.5
HWRF O&M	$1M*	$0.5M	$1M	$1M	$1M
Development	-	-	$11M* $3M	$13M	$13M
NOAA DTC**			$1M	$3M	$3M
R&D Computing	-	-	$6M*	$3M	$3M
Total	**$6.3M**	**$8M**	$29.5M	$27.5M	$27.5M

* **Supplemental Appropriation**
** **Includes support for broader WRF Program; Joint with AF**

HFIP Project
Important Linkages

- NOAA Operational Hurricane Observing Program

- Joint Center for Satellite Data Assimilation – (Leverage $3.4M)

- National Unified Operational Prediction Capability for Operational Global Ensembles

- NOAA's National Ocean Service coastal, estuary, and inundation modeling program

- WRF Developmental Testbed Center (DTC) – Leverage DTC capabilities ($3.0M in FY10)

- Leverage The Observing System and Predictability Experiment (THORPEX) sponsored activities [North American Ensemble Forecast System (NAEFS), predictability research] ($1.3M)

- U.S. Weather Research Program - Support of Joint Hurricane Testbed and DTC Activities in FY08-10

- Navy partnership in atmospheric (global and hurricane), oceanic, and wave modeling

- Leveraging operational development and upgrades (GFS, HWRF)

High Performance Computing Augmentations

- **2008:**
  - Texas Area Computing Center (TACC): 15M hours
- **2009:**
  - NJET (Boulder System): ~2M hours/month starting 9/2009
  - TACC: 20M hours from 7/1 – 12/31
  - TACC: Penn State separate 13M hours allocation for High Resolution ARW Ensembles and Data Assimilation
  - NOAA R&D Computer in Gaithersburg: 115K hours/month
  - NCEP backup computer (Cirrus): Used for HWRF testing
- **2010 – Planned:**
  - NJET: ~2M hours/month
  - NJET: ~+3000 additional processors beginning 7/1/2010
  - Dept of Energy, Oakridge National Laboratory (Jaguar): 20M hours
  - TACC: 2.5M hours from 1/1 – 6/30

NWS Operational System Upgrades

- Global Forecast System upgrades **(Dec 2009)**
  - Added tropical storm pseudo sea-level pressure observations
  - Additional observations (NOAA Polar Orbiting Satellite Obs: Infrared Sounder/Advance Microwave Sounder/Microwave Humidity Sounder/Brightness Temp; European Organization for the Exploitation of Meteorological Satellites: Atmospheric Motion Vectors, etc.)

- GFS upgrades **(May 2010)**
  - Resolution increase (27 km from 38 km)
  - Improved Physics (radiation, gravity wave drag, mountain blocking, shallow convection, Planetary Boundary Layer (PBL), deep convection with overshooting cloud tops)
  - Removal of computational artifacts e.g.: negative water vapor

- HWRF upgrades (**May 2010**)
  - Upgrade surface exchange coefficients
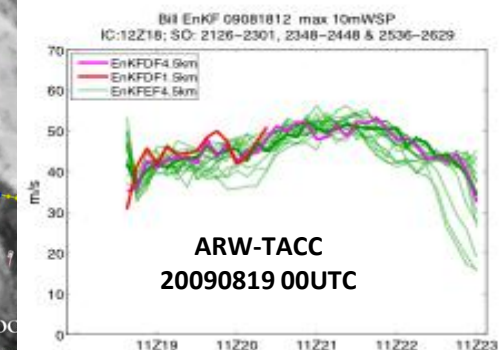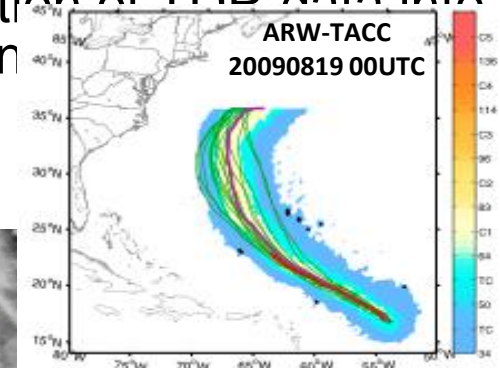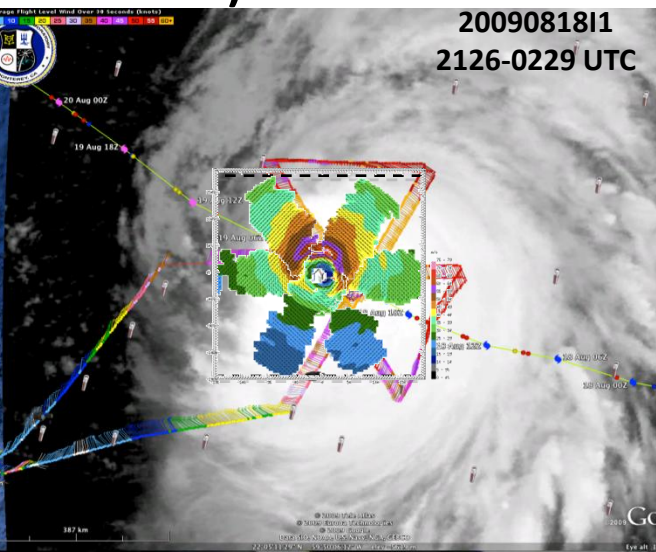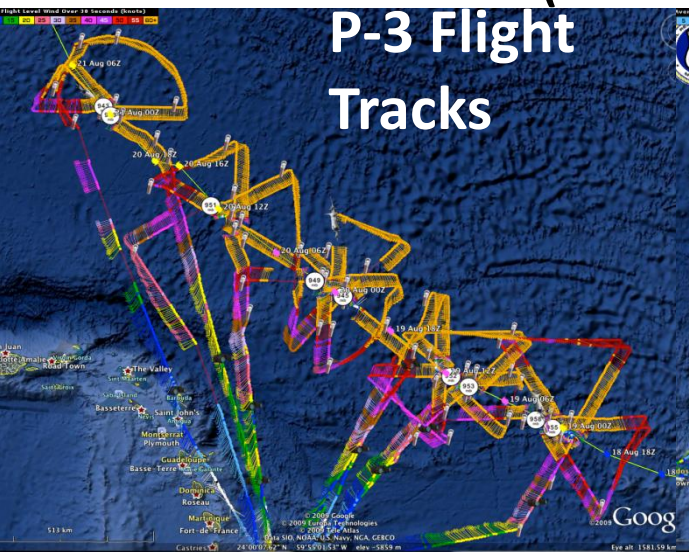 - Coupling with HyCOM ocean model

- IFEX 2009: WP-3D (17 missions, all 1 P-3/double crew) and G-IV (14 missions) with HRD crews flew ~200h to gather data in Hurricanes Paloma (2008) and Bill, plus Tropical Storms Ana & Danny
- Deployed 756 dropwindsondes and 238 expendable bathythermographs (AXBTs). 55 real-time Tail Doppler Radar (TDR) analyses transmitted to NHC and Doppler radial files transmitted to EMC. TDR superobs transmitted in Paloma, Bill and Danny provided real-time assimilation of TDR data into ARW model at TACC. ~60 real-time H*Wind surface an

Hurricane Bill: 5 missions at 12-h intervals

00Z 19–21 August collecting Doppler SO

(ARW-TACC EnKF)

ARW-TACC 20090819 00UTC

P-3 Flight Tracks

20090818I1
2126-0229 UTC

Bil EnKF 09081812 max 10mWSP
IC:12Z18; SO: 2126-2301, 2348-2448 & 2536-2629

EnKFDF4.9km
EnKFDF1.9km
EnKFEF4.5km

ARW-TACC 20090819 00UTC

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FY10 Observational Programs

- NOAA'S Hurricane Intensity Forecast Experiment (IFEX) 2010:
  - 2 NOAA WP-3D, G-IV – 700 flight hours (1 June-30 November)
  - N42RF will be available by early June; N43RF available early August; N49RF (G-IV) available early June
  - Crews available 2/day missions starting July (Tampa and deployments)
  - Base from Tampa, FL; St. Croix, USVI; & Barbados
- NASA Genesis and Rapid Intensity Processes (GRIP):
  - DC-8 and Global Hawk (GH) – 200 flight hours (15 August-30 September)
  - Base Ft. Lauderdale, FL (DC-8); Edwards AFB (GH)
- NSF Pre-Depression Investigation of Cloud-systems in the Tropics (PREDICT):
  - G-V (HAIPER) – 200 flight hours (15 August-30 September)
 - Base St. Croix, USVI

Encouraging Findings from FY09

- Higher order data assimilation systems [The Ensemble Kalman Filter (EnKF) and the four-dimensional variational data assimilation (4DVAR)] very significantly improve global forecasts over the current operational data assimilation system:

  - 10-20% improvement in forecasts of tropical winds, and
  - 15% improvement in track at 5 days.

- High resolution ensemble systems (global and regional) are showing improvements in track and intensity as expected.

- High resolution global ensembles (30 km, 20 members) can be run in real-time on available computing resources. Higher resolution is definitely possible.

- Airborne radar data used to initialize the hurricane vortex in regional models significantly improves forecasts of track and intensity:

  - Initial Results show ~15-20% improvement both in track and intensity.
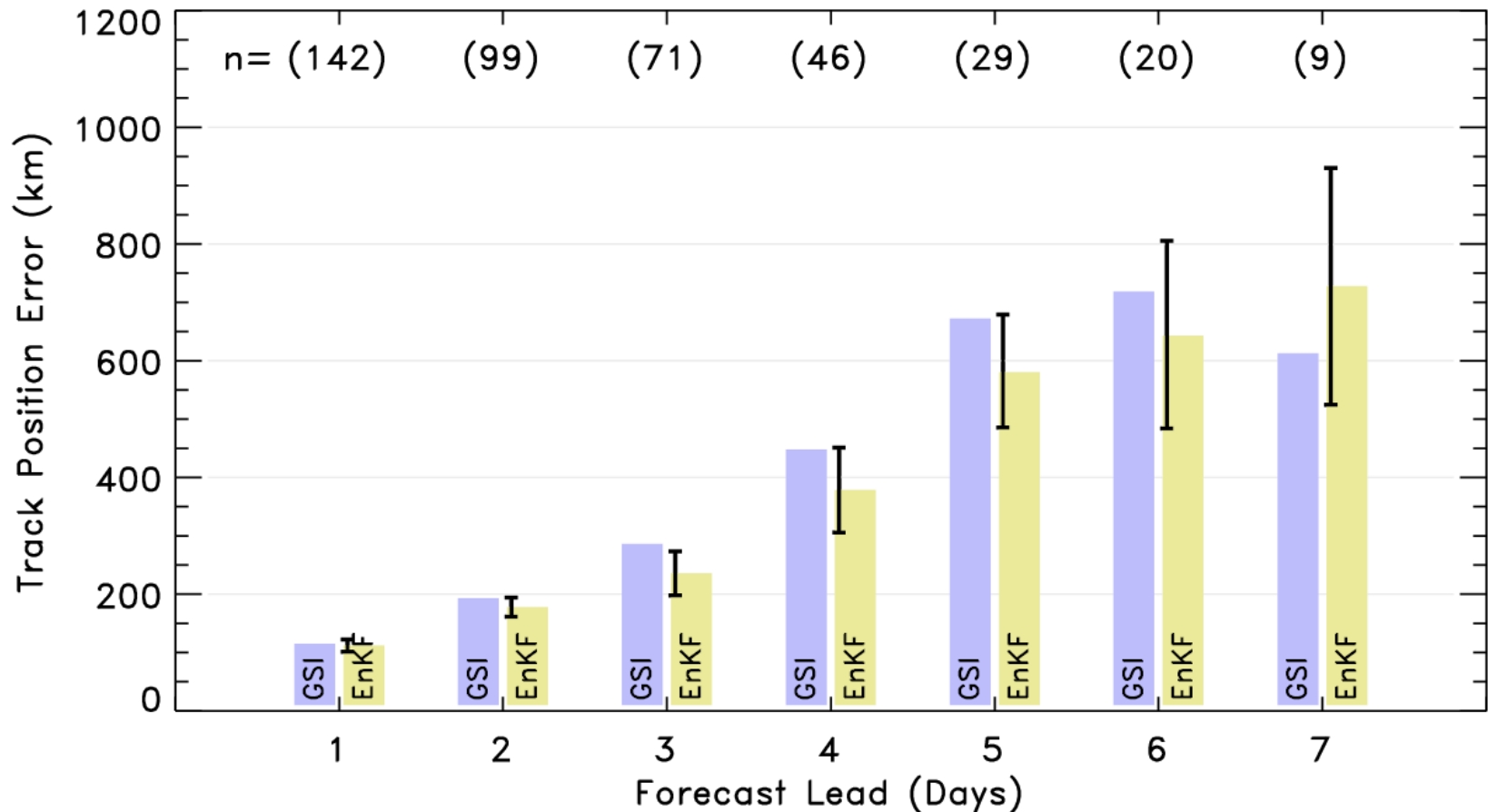
TR Wind Forecast Verfication
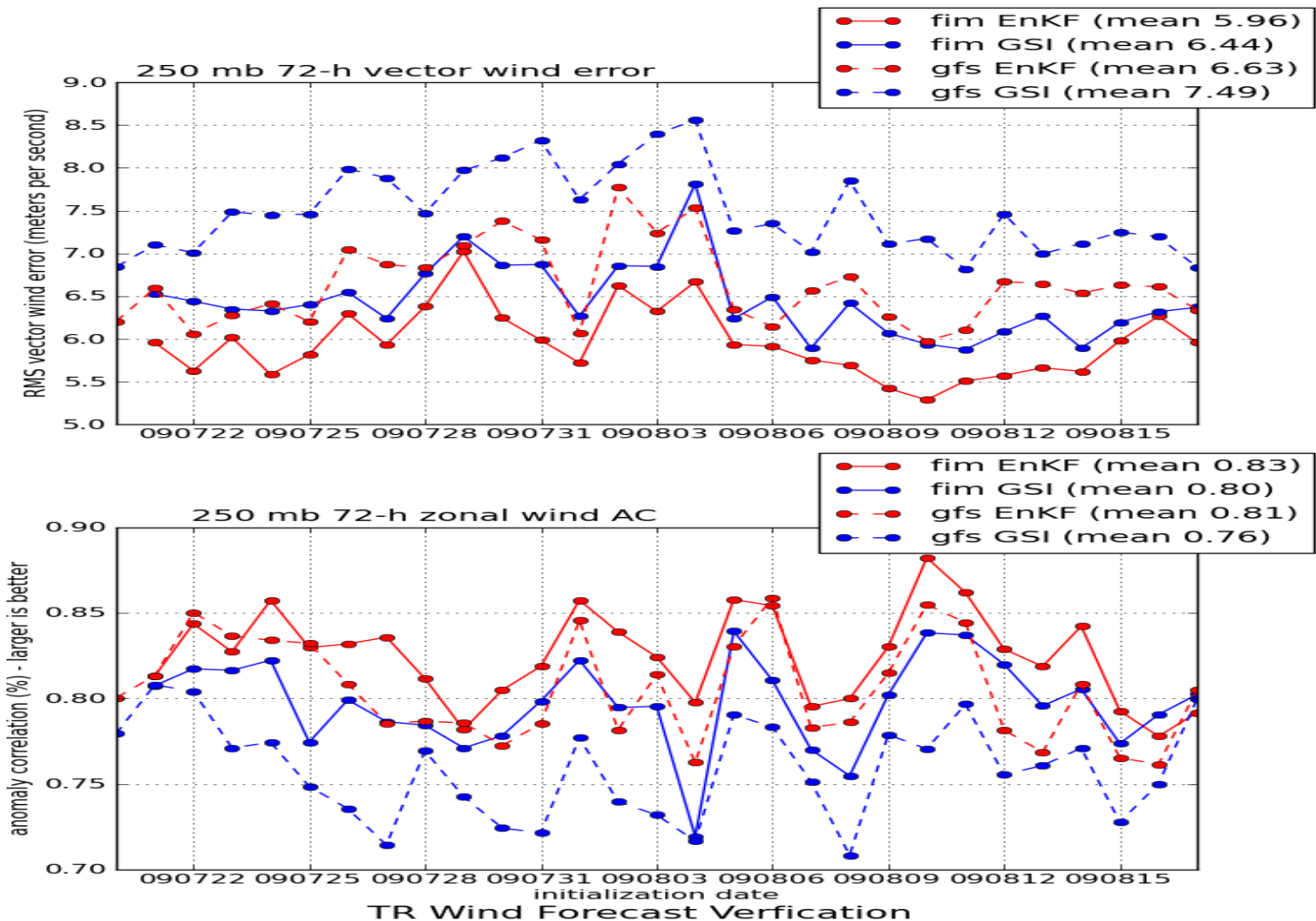
Changes in Track Forecast Error using GSI vs. EnKF

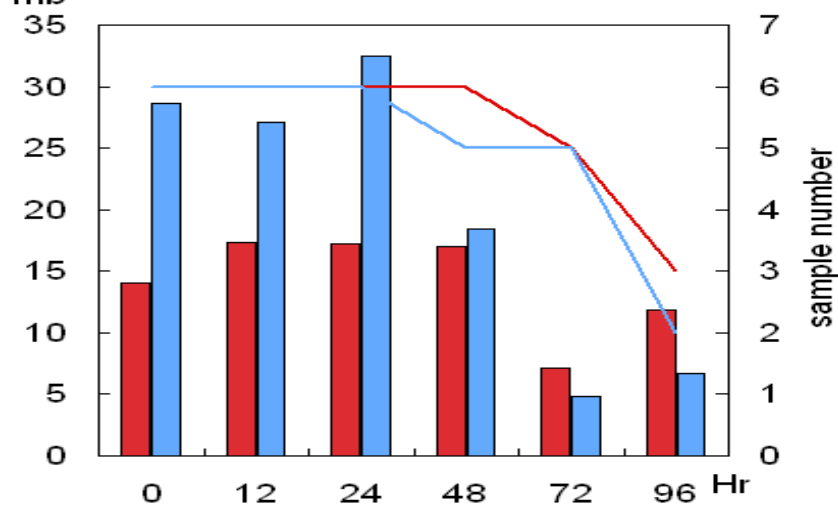Deterministic 15-km FIM GSI **and** EnKF Track Errors
20090715 to 20091004

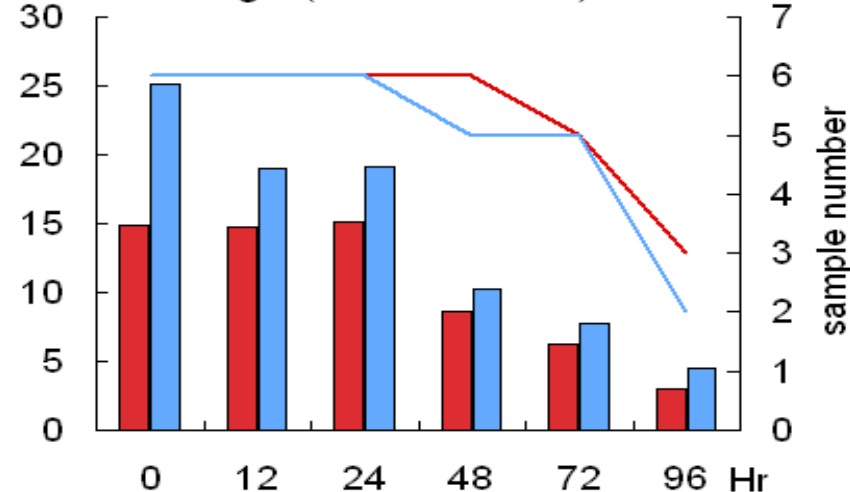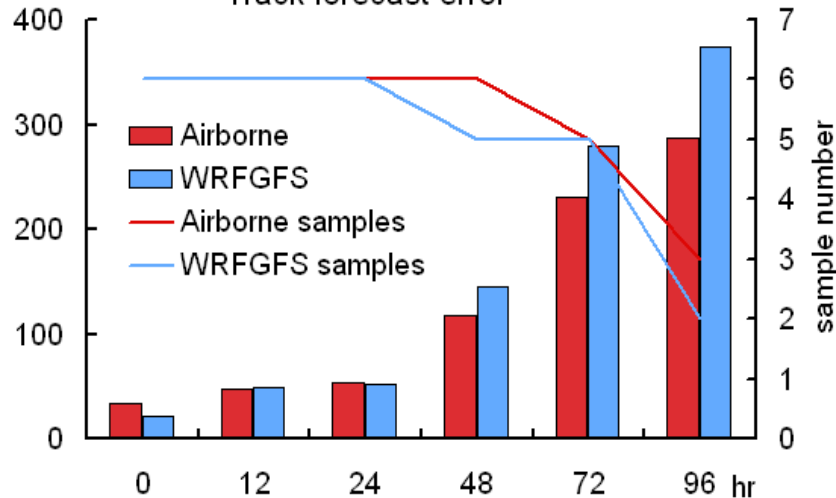# Forecast Error with Airborne Radar Derived Radial Velocities vs. w/o

Note that sample size is very small; but, it does indicate a significant improvement in intensity out to 48 hours and track at 4 days.

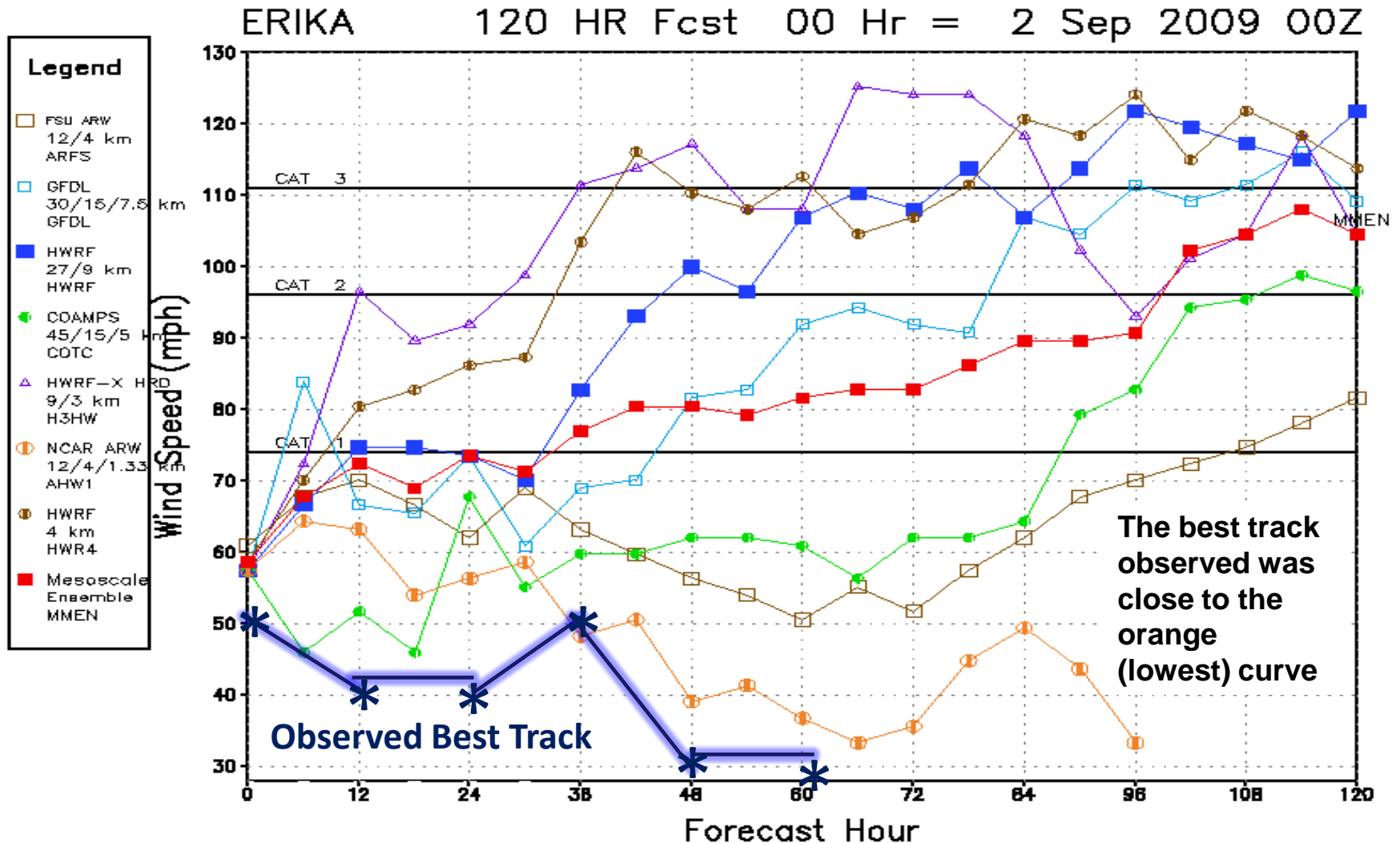**Yonghui Wen and Fuqing Zhang at PSU**

Lessons from FY09

- There is a major problem with initialization of regional models.
  - This was particularly apparent with the highly sheared storms that characterized this hurricane season.

- Both the regional and global models greatly (by a factor of at least 2 to 3) over-predict genesis.

- Simply increasing the resolution of the regional models alone does not lead to improvements in model guidance.
  - Clearly demonstrated High Resolution Hurricane (HRH)—conclusions:
    - Increased resolution did not substantially improve forecasts for any model.
    - May need better physics and/or initialization to realize benefits of higher resolution.

- Conveying the value and use of ensemble information to the forecast community.
  - Need to engage the community to produce new products that forecasters find useful.

ERIKA   120 HR Fcst   00 Hr =   2 Sep 2009 00Z

The best track observed was close to the orange (lowest) curve

Observed Best Track

Challenges for HFIP

- A vast majority of model forecasts will be initialized for storms with no aircraft data available.

- Development, testing, and evaluation of physics packages for global hurricane models at higher resolution is critical.

- Improved intensity prediction at higher resolutions requires additional physics development.

- High resolution global and regional ensemble systems are showing promise, but require further testing and evaluation.

- We need to develop better products to convey ensemble information to forecasters.

- We need to ensure future operational computer power is available for transfer to operations.

Challenges for HFIP
Improving Intensity Forecasts

- Early results indicate that even with ensemble approaches intensity predictability extends only 2-3 days. However:
    - Half of the intensity changes are likely related to changes in the hurricane environment:
        - Ocean
        - Surrounding atmosphere
    - These may be predictable using coupled ocean-atmosphere global models:
        - Use of global model ensemble information in constructing regional ensembles
        - Use of statistical methods coupled with the regional and global ensembles
    - Intensity changes related to internal core dynamics may not be predictable beyond 1-2 days:
        - And only then if the near core parts of the hurricane are accurately initialized

Key HFIP FY2010 Near Term Priorities
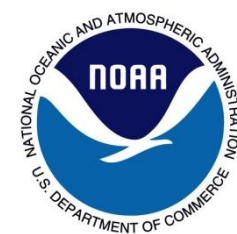
- Implement T574 (~27km) GFS Operationally

- Implement HWRF upgrades

- Focus on developing hybrid data assimilation for global and hurricane applications

- Improve Model Initialization and Physics

- Acquire additional R&D and Ops computing

- Demonstrate 4km hurricane model ensemble (NHC*)

- Demonstrate Global Model Ensemble -15km resolution (NHC*)

- Participate in GRIP and Predict with NASA and NSF

- Support effort for quantifying economic impact of improved hurricane forecasts

NHC* - Send output to NHC in near-real time

Desired Outcomes

- SAB informed of NOAA progress in addressing need to significantly improve hurricane forecasts

- Improved Communication with SAB

Backup Slides

HFIP 2009
Hurricane Season Activities

Global Models:

- 30 km EnKF Data Assimilation System run during August and September

- FIM Deterministic Models run each day during Aug-Sep:
    - 30 km (Initialized with GSI-3DVAR and EnKF)
    - 15 km (Initialized with EnKF)
    - 10 km (Initialized with EnKF) - started August 15

- Global Ensembles:
    - 30 km FIM (Initialized with EnKF) 20 members
    - 27 km GFS (Initialized with GSI-3DVAR) 5 members
    - 55 km NOGAPS (3DVAR then 4DVAR), 9 members

<u>Regional models:</u>

- Multi Model Ensemble (various initialization schemes):
  - (Run for all storms - Not all models present for all run times)
    - a) HWRF   9km
    - b) HWRF   4km
    - c) GFDL   7.5km
    - d) HWRF-x   3km
    - e) WRF/ARW/NCAR   1.3km
    - f) WRF/ARW/FSU   4km
    - g) TC-COAMPS   5km
  - Single model Ensemble (Run for most storms) – Separate allocation from TACC
    - a) WRF/ARW/PSU   4.5 km   30 members
      1) Initialized with an EnKF system
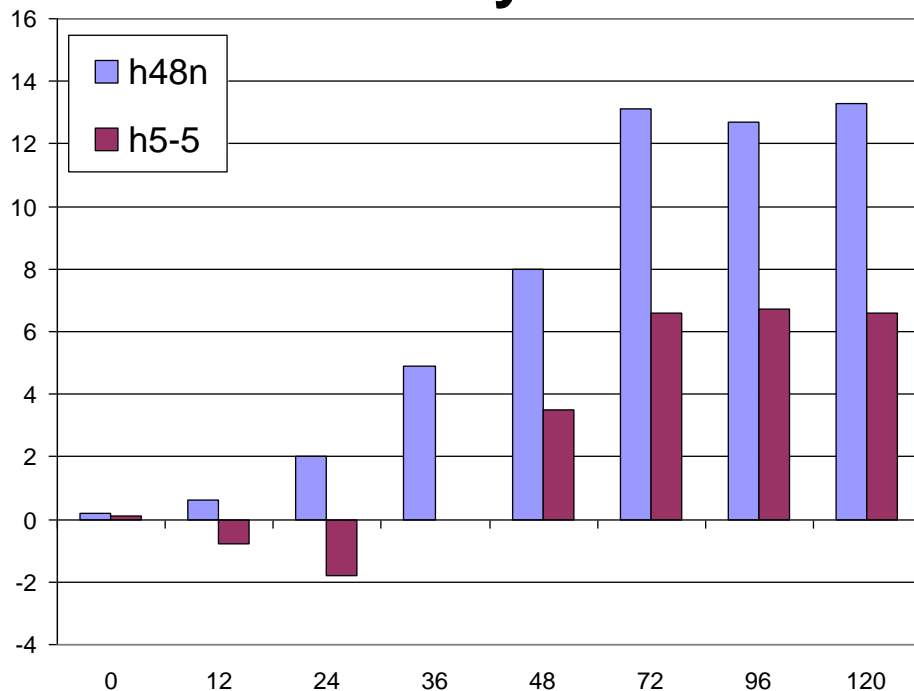   2) Initialized with P3 radar data when available

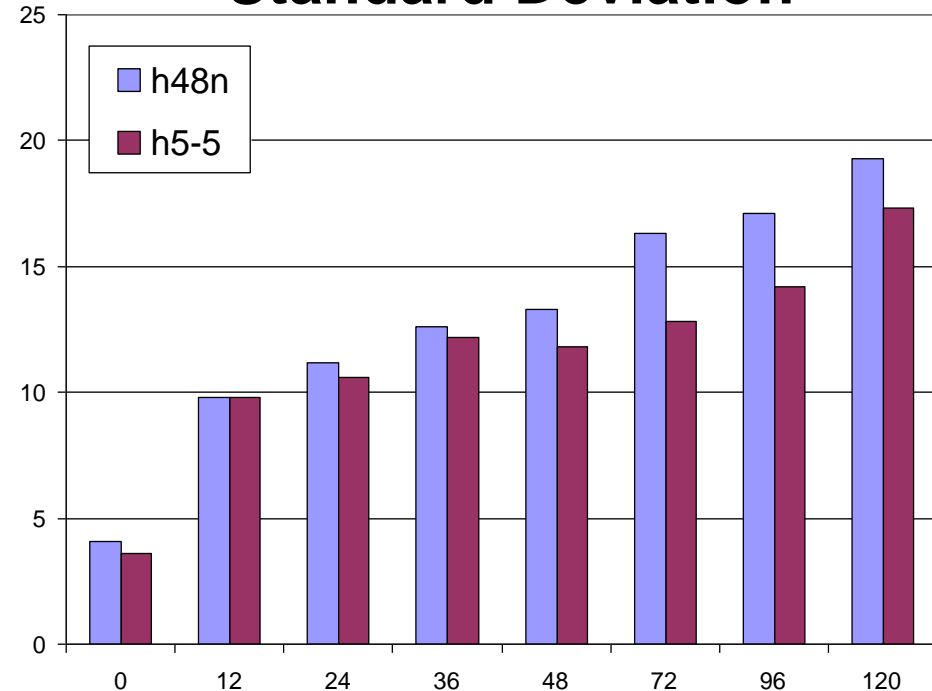# Impact of Upgraded Surface Flux Parameterization on HWRF Intensity Forecasts

Modification of HWRF Air-Sea Exchange Coefficients

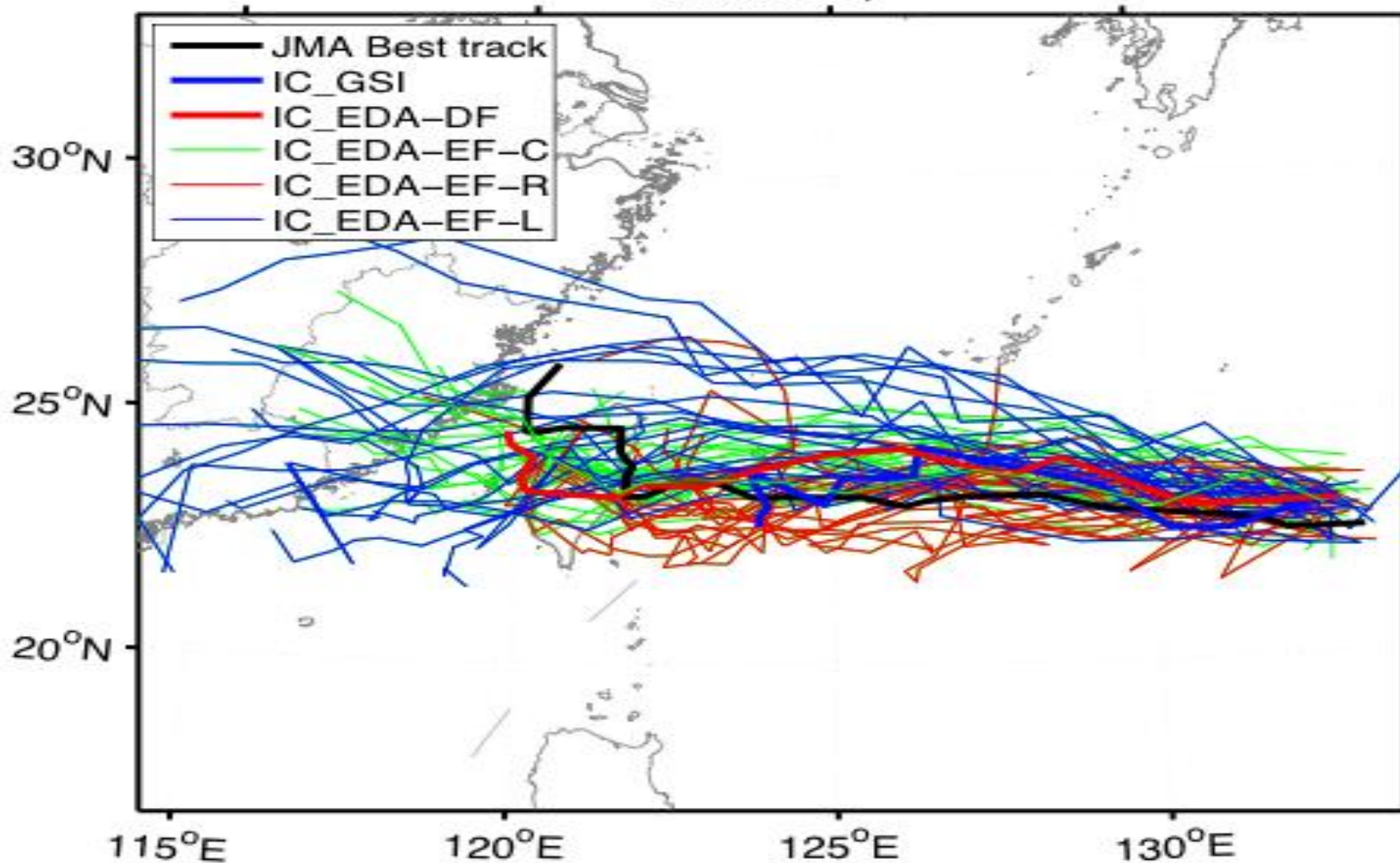**Intensity Bias** and **Standard Deviation** charts with legends h48n and h5-5, plotted against forecast lead time (0, 12, 24, 36, 48, 72, 96, 120).

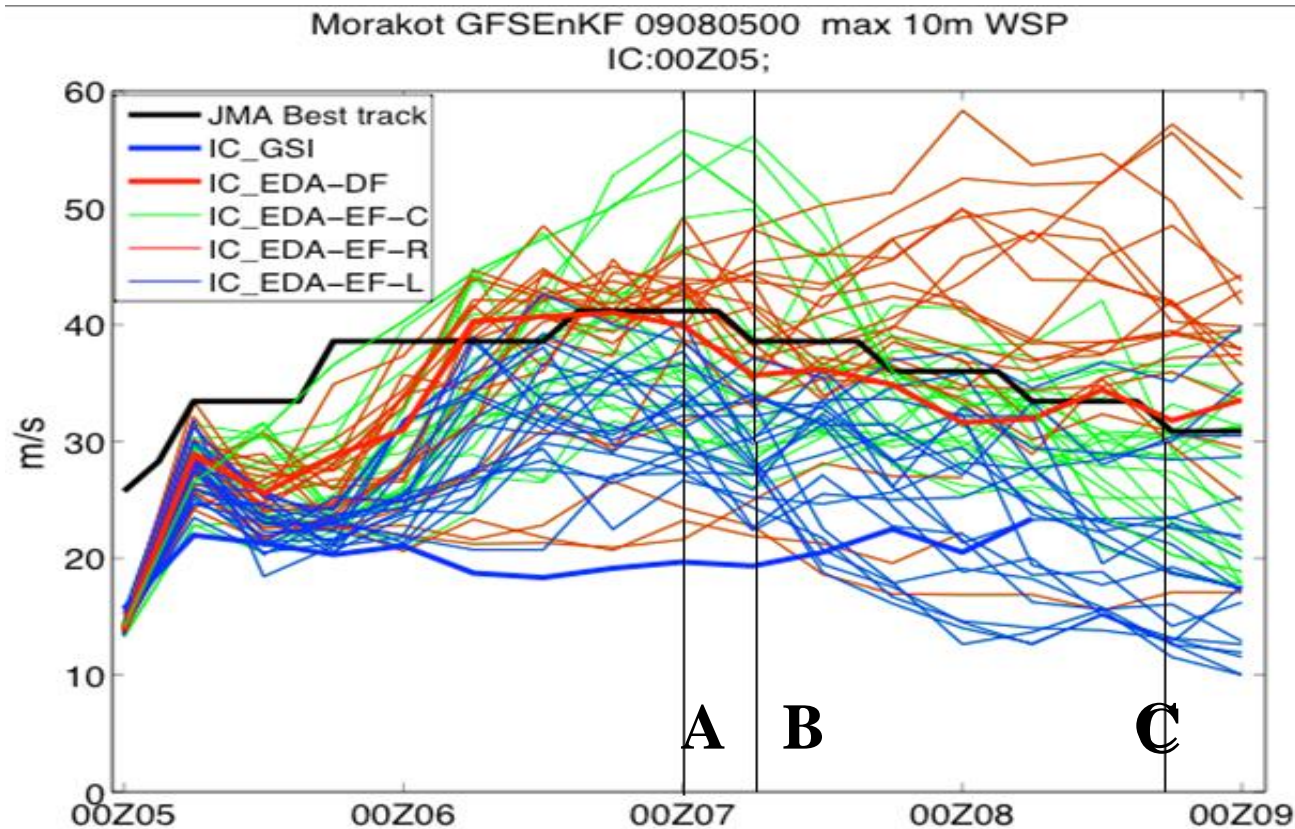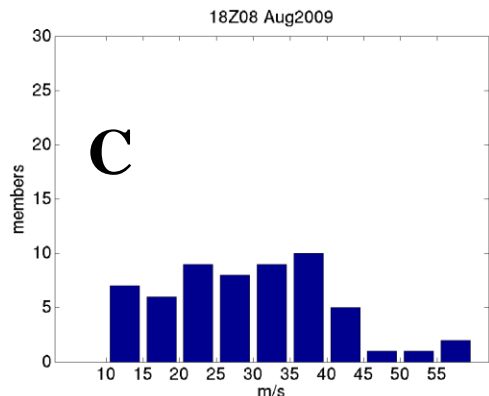**Reduction in HWRF intensity bias and standard deviation for longer lead time guidance**

Morakot GFSEnKF 09080500 Track
IC:00Z05;
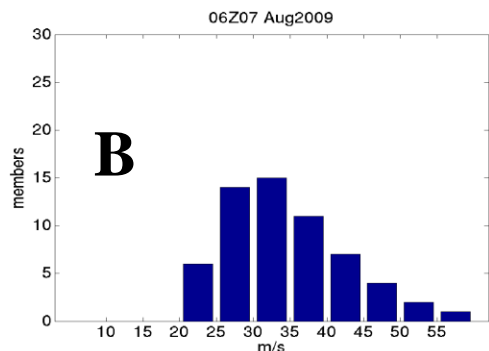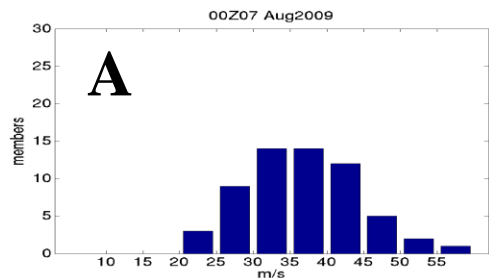
Intensity PDFs (A, B, C) Indicate weakening over six hour period after 48 hours: A to B. By 90 hours, C, skill in the ensemble intensity forecast has been lost.

3/17/2010

Hurricane Track Error Comparison – Atlantic 2008
Cristobal_Dolly_Fay_Gustav_Hanna_Ike_Omar_4cyc
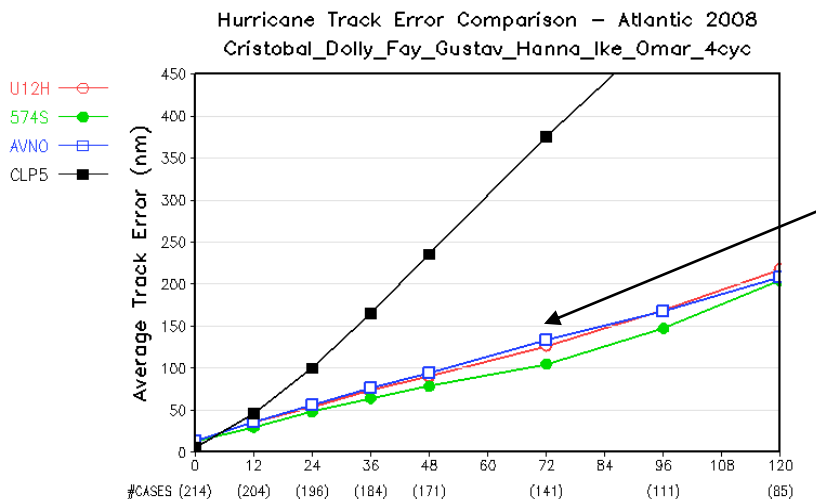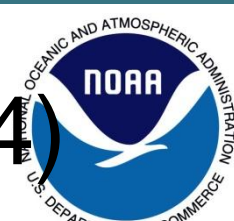
2008 Operational – Blue
December GFS Package – Red
T574 with upgraded Physics - Green

ATL 20% improvement at 72 h

Hurricane Intensity Bias

Hurricane Track Error Comparison – East-Pacific 2008
20080602__20081110__4cyc
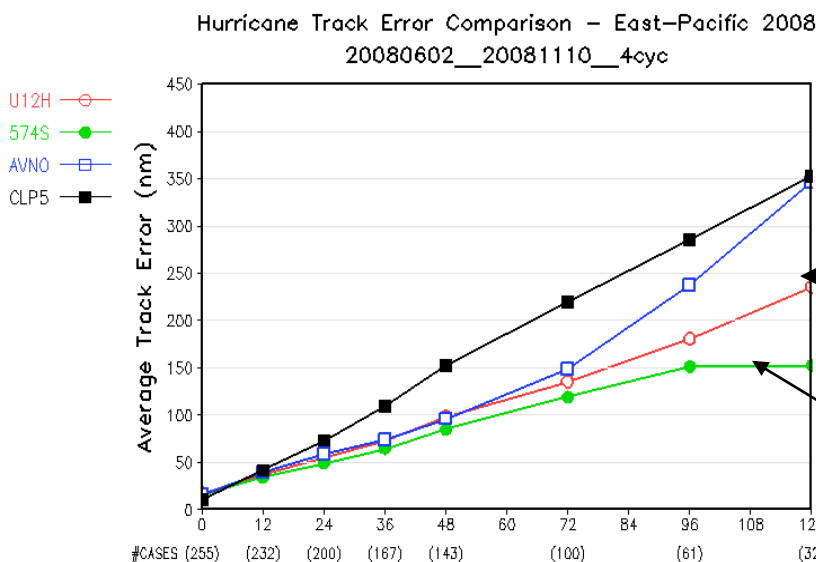
32% Improvement over 2008 Prod (Fig A)

35% Improvement over 1Q10 Prod

Major impact on GFS intensity bias and skill (ATL and EPAC)

EPAC impact at all forecast projections

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NOAA HFIP R&D Strategy

- **Research:**
  - NOAA Program
    - Focus NOAA effort which complements and supports external (non-NOAA) research
    - Encourage external participation with grants program
    - Visiting scientist program at NOAA offices
  - External
    - Support creation of National Hurricane Research Alliance of federal labs and academia, including potential NSF sponsored centers
    - Coordinate basic and applied research with national basic and applied research agenda (OFCM Lead)
- **Research to Operations:**
  - Strengthen critical research and development, test and evaluation, infrastructure, and process
    - DTC, Joint Hurricane Test-bed, and storm surge model test-bed
    - R&D Computing dedicated to hurricane research and forecast technology improvement
  - Adopt common modeling architecture for research and operations

HFIP/Storm Surge Roadmap Strategy for Enterprise Improvement

- Surge key aspect of hazard - Biggest tropical cyclone losses
- Roadmap enhancements will amplify HFIP outcomes by enabling more accurate and timely warning of TC hazards
- HFIP supporting Roadmap goals by improving surge modeling to higher res predictions of total water level above ground
- Roadmap conducting social science studies and has team to improve surge warnings

$M	FY09	FY10	FY11	FY12	FY13	FY14	FY15
	Enacted	Pres. Request	Based on FY11 Programming or Current Programming in PIRS, PPBES				
HFIP – Storm Surge R&D (MOBI/WW)	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5	$0.5
HFIP – Storm Surge O&M (MOBI/WW)	$0.3	$0.3	$0.3	$0.3	$0.3	$0.3	$0.3
Resilience (MOBI/WW): Community Modeling Risk Communication			$1.08 $1.365	$1.08 $1.365	$1.08 $1.365	$1.08 $1.365	$1.08 $1.365
IOOS Inundation Projects (MOBI)	~$2.2M (FY07-09)	Proposal based	Portion of $4 test-bed				
Ocean Research Priorities Plan – Extreme Events Near Term Priority (CEO/WW)		$0.5 directly to roadmap	$5* (*$2 to Sea Grant)	$5*	$5*	$5*	$5*
In Kind Resources:	NOS (CO-OPS, CSDL, CSC), OAR (NSSL, ESRL – computing), NWS (NHC, MDL, NCEP, WFO), IOOS						

2009 Hurricane Season Operational and Demonstration Systems

Operational Model Suite	Demonstration System
• **Global Model:** GFS T382 (~35km), 64 layers	• **Global Model:** FIM 10km,15km, 30km, 64 layers
• **Global Ensemble:** GFS T126 (100km), 28 layers, 20 members (40 with NAEFS); FIM will be tested at 60km when ported	• **Global Ensemble:** FIM 30km, 20 members; GFS T574 (~27km), 5 members; NOGAPS 55km 9 members
• **Regional Model:** No upgrade for 2009 season. HWRF 9km, 69 levels, coupled ocean (POM)	• **Regional Model Ensemble:** ARW, 4.5km, 30 members
• **Regional Ensemble:** 35-45km, 28-51 layers, multi-member ensemble **(ARW, NMM, RSM, ETA)** 21 members (non-hurricane model fixed domain)	• **Multi-Model Regional Ensemble:** 1.3km - 9 km, 36-43 layers, multi-member ensemble (ARW (two versions), MMM, HWRF, HWRF-X, COAMPS-TC, GFDL, HWRF 4km)
• **NHC Consensus Ensemble:** Track **(GFSI, EGRI, NGPI, GFMI, HWFI);** Intensity **(DHSP, LGEM, GHMI, HWFI, GFNI)**	• **Data Assimilation Global:** GSI-3DVAR, EnKF, 4DVAR
• **Data assimilation, Global:** GSI-3DVAR	• **Data Assimilation Regional:** EnsKF (with Tail Doppler data when available)
• **Data assimilation regional:** GSI-3DVAR	

HFIP Team: University and External Community Involvement

#	Organization	HFIP ($K)	NOAA Ear-Mark ($K)	JHT ($K)
1	Univ. of WI	50		59
2	Penn State	210		
3	Univ. of AZ	102		
4	URI	190		163
5	MMM	200		
6	NCAR/DTC/ JNT	1430		
7	NRL	1000		94
8	SUNY-Albany	60		
9	FSU	100	1413	
10	Colorado State Univ.	150		35
11	Univ. of Miami		500	232

NOPP Funding

PI / Partner(s)	Institution	Funding
Schubert	CSU	$227,819
Velden	U. Wisc.	$408,797
Chen, S.	U. Miami	$350,784
Ginis	URI	$350,000
Reeder	Monash	$362,100
Tyo	U. Arizona	$266,512
Miyoshi	U. Maryland	$267,184
Chen, Y.	York U.	$125,320
	Total:	**$2,358,516**

Hurricane Forecast Improvement Project
and
Hurricane Intensity Research Working Group (HIRWG) Reports

HIRWG and HFIP Summary

Most HIRWG (majority and minority) recommendations were addressed by the HFIP or already being addressed in NOAA:

- A few HIRWG recommendations are being addressed by NOAA outside of the HFIP.

- NOAA suggests three of the recommendations be led by other entities outside of NOAA.

Majority/Minority Report conflicting approaches on modeling:

- HFIP follows majority report recommendation.

    - *High-res model concept must be evaluated.*

- Simplified models represent another external research opportunity.

Response to HIRWG Recommendations

Majority Overarching Priority (higher priority recommendations in blue):

1) **NOAA should allocate sufficient resources and provide national leadership to enable the high-priority research-and-development activities recommended to be undertaken at a sufficient level to ensure positive outcomes. This funding should be for a minimum of five years, and should be protected against other budgetary pressures.**
   - The HFIP Plan:
     - Establishes specific action items and milestones, with clear lead responsibilities
     - Identifies performance measures
     - Identifies funding requirements for all elements that build on the investments already in the FY08 and FY09 budget planning (TBD)
     - Ensures comprehensive treatment of modeling, testbeds, observational strategies, high performance computing, emerging systems, and platforms
     - Identifies opportunities and needs for coordination with other Federal agencies and the external community
     - Identifies research-to-operations activities that need to be executed in parallel in order to assure adequate infrastructure resources

I. Define and build an enhanced Hurricane Forecast System/Global Forecast System (higher priority recommendations in red):

- **Majority (2, short term) Better use of coupled models** - HWRF implemented in FY07, upgrade to fully coupled HWRF in mid-term, continue improvements for high-res HFS

- **Majority (3, short term) Computing capability for 1-km horizontal resolution forecasts** - Planned with demonstration using DOE HPC, on demand capability mid-term, sustained long-term

- **Majority (4, medium term) 4D data assimilation** - Investigate possible DA approach (also EKF, hybrid)

- **Majority (8, short term) and Minority (2) Rapid Intensification near landfall** - New metric's developed in FY07, focus of HFS development for mid-term

- **Majority (9, short term) HRD Modeling capability** – Addressed in FY08 budget, mid-term additions as needed

- **Majority (10, short-term) DTC adequately funded** - Started in FY07 under USWRP, increase in short-term, one of main strategies in mid- and long-term

- Majority (11) HWRF Version 1 implemented in FY07, with upgrades in short-term

- Majority (13) 3DVar - GSI in FY07, planned as part of HWRF short-term implementation, continued development as needed mid- and long-term for high-res HFS and next generation GFS

- Majority (20) Ensemble Forecasting - Planned for HFS/GFS to reduce uncertainty

- Majority (21) DTC and JHT to a wider community - One of main strategies mid- and long-term

- Majority (22) JHT funding increases - One of the main strategies mid- and long-term

Response to HIRWG Recommendations

II. Observing strategy development (higher priority recommendations in red):

- **Majority (5, short-term) Inner core radar data assimilation** - Planned development in short-term, continue as needed mid- and long-term for high-res HFS

- **Majority (6, medium term) Satellite observations Assimilation -** Strategies are planned for testing mid- and long-term as needed (XOSVW, NPP, NPPOES/METOP, GOES-R) - expand JCSDA to focus on TC core observations

- **Majority (7, short term) Airborne expendable bathythermographs** - Expendables are budgeted for each year mid- and long-term

- Majority (12) Field Experiments for high-Res Models - Planned for mid- and long-term

- Majority (14) OSSE's optimal observing strategy - One of main tools for observing strategy analysis mid- and long-term

- Majority (15) G-IV /SFMR on USAF - Implemented on USAF in short-term, G-IV in short-term, observing strategy examined in mid-term

- Majority (17) and Minority (5) "swarm of LALE UAS's" - Possible observing strategy for testing under HFIP

- Majority (18) OSSE for optimal oceans observations - Possible observing strategy for testing under HFIP

- Majority (19) Assimilate airborne and surface Radar data - Planned short-term development, continue as needed mid- and long-term for high-res HFS

Response to HIRWG Recommendations

III. Expanded forecast tools and applications to provide a value-added resource to the hurricane forecasters:

- Majority (24) High res impacts on warnings - Not explicitly addressed, but ideal to be addressed through expanded JHT
- Majority (25) Develop and test reduced models and stats - Not explicitly addressed, but ideal to be addressed through expanded JHT
- Majority (26) Archive data and more readily available - Must be addressed to support expanded JHT
- Majority (27) Comprehensive verification - Started, high-res HFS in mid- and long-term, should be addressed through expanded JHT
- Majority (28) Remove ocean and surge from Saffir-Simpson - Not high priority but could be addressed through expanded JHT
- Majority (29) More complete suite of forecast parameters - Should be addressed through expanded JHT
- Minority (1) develop mesoscale models with simpler numerical/analytical predictive tools - Not explicitly addressed, but ideal to be addressed through expanded JHT
- Minority (4) adopting a model for each secondary effect that is accurate and simplistic - Not explicitly addressed, but ideal to be addressed through expanded JHT

HIRWG Recommendations *Not* Addressed by HFIP

NOAA Takes Majority Report Recommendation on Modeling (minority report recommendation conflicts with majority report):

- Minority (3) Avoid High-res models for simplified models - *Consensus was that the high-res model concept must be evaluated*. Basis of HFIP plan is to demonstrate high-res model utility and to address predictability issues raised in minority report.

Addressed Elsewhere in NOAA:

- Majority (16) and Minority (5) Committee for UAS to develop NOAA strategy - NOAA is addressing this recommendation outside the HFIP - NOAA UAS committee formed, hurricane demonstrations implemented starting in FY07 - *OSSEs are part of HFIP.*

- Minority (8) NHRL (restoration) - NOAA is addressing this recommendation outside of HFIP.

Better addressed outside of HFIP:

- Majority (23) Multidisciplinary approach (science/social) - Better addressed outside of HFIP, through NHRI, OFCM, etc.

- Minority (6) Laboratory integration of field experiments - Better addressed outside of HFIP, through NHRI, OFCM, etc.

- Minority (7) Heat transfer experiments –wind tunnel etc. - Better addressed outside of HFIP, through NHRI, OFCM, etc.

HFIP Portfolio*
(from Fall 2007 Briefing)

I. **IMPROVE** Hurricane Forecast System/Global Forecast System **TO REDUCE ERROR IN INTENSITY AND TRACK FORECASTS**

II. **OPTIMIZE** observing systems **TO ENHANCE** research and operations **CAPABILITIES AND IMPACTS**

III. **EXPAND AND IMPROVE** forecaster tools and applications **TO ADD VALUE TO MODEL GUIDANCE**

* Addresses most HIRWG Recommendations

Short Term Actions: Priorities and Payoffs

- **High Resolution Model and Other Model Enhancements:**
  – Technical staff with modeling and software engineering expertise
  – R&D for HFS/GFS to demonstrate, using DOE HPC system, high resolution and ensemble prediction capability and address data assimilation challenges
  – Planned HFS/HWRF R&D and upgrades sustained
  – Storm Surge Testbed
- **Enhance HPC Capability:**
  – NOAA R&D computing to support HFS/GFS development including software engineering
- **Research to Operations (R20) Enhancements:**
  – Increase funding for the JHT (includes staffing)
  – Increase support for the Developmental Testbed Center (DTC) and Joint Center for Satellite Data Assimilation (JSCDA)
  – Targeted field programs and operational flights
- **Broaden expertise and expand interaction with external community:**
  – Establish a visiting scientist/Post Doc program
  – Advisory committees, community workshops
  – Permanent HFIP Staff and infrastructure

PAYOFFS:
- Staffing and computing infrastructure established to evaluate potential model improvements
- Targeted high resolution and ensemble model research and development funded
- Demonstration completed on the impact of forecast performance using the high resolution model system on DOE system– decision point for NOAA HPC investment
- Upgrades to HFS/HWRF implemented operationally, and HFS/HWRF on a path to 4km resolution
- Storm surge testbed established
- Staff and infrastructure established for enhanced transition of research to operations
- Broaden community expertise through visiting scientists at operational centers
- Involvement with external community for modeling R&D and development of forecast tools through JHT, DTC, and JCSDA
- Permanent staff for HFIP

Engagement of external community

- **High Resolution Model and Other Model Enhancements:**
  - Implement the higher resolution HFS and GFS for operations including associated IT infrastructure in an on-demand capacity on DOE system
  - Implement next generation storm surge model(s)/ensembles
  - Sustain HFS/HWRF model research and development

- **Enhance HPC Capability:**
  - Ramp up HPC investment for sustained NOAA operations, based on input from the HPC demonstration period

- **R20 Enhancements:**
  - Establish observing system analysis capability, including demonstration, evaluation, transition, operations and maintenance, and related data assimilation challenges
  - Maintain increased levels of support for the JHT, DTC, and JCSDA

- **Broaden expertise and expand interaction with external community:**
  - Ongoing external community involvement in NOAA operational and research facilities

PAYOFFS:

- Operational implementation of a high resolution model system and next generation storm surge model in on-demand mode from DOE systems

- Operational implementation of a 4km HFS/HWRF

- Optimized process established to advise NOAA on observing investment decisions

- JHT projects available for operational use and IT infrastructure upgraded for efficient transition, yielding enhanced forecast tools and modeling improvements

- New generation of operational modelers and tropical expertise underway

- Community involvement in evaluation of HFIP

Long Term Actions: Priorities and Payoffs

- **High Resolution Model and Other Model Enhancements:**
  - Continued improvements to the high resolution HFS and GFS for operations including associated IT infrastructure
- **Enhance HPC Capability:**
  - Sustained operational HPC capability for high resolution models
- **R2O Enhancements:**
  - Sustained end to end transition process
- **Broaden expertise and expand interaction with external community:**
  - Ongoing process for external community involvement in NOAA operational and research facilities

PAYOFFS:

- Healthy NOAA modeling and IT infrastructure for operations
- Fully high resolution HFS/GFS sustained on sustained NOAA operational High Performance Computing
- Integration of long lead observing improvements
- Next generation of tropical experts and modelers
- Forecast improvement goals met and customer needs addressed